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THE STELLAR ANCESTRY OF SUPERNOVAE IN THE MAGELLANIC CLOUDS - I. THE MOST RECENT SUPERNOVAE IN THE LARGE MAGELLANIC CLOUD

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ABSTRACT

We use the star formation history map of the Large Magellanic Cloud recently published by Harris & Zaritsky to study the sites of the eight smallest (and presumably youngest) supernova remnants in the Cloud: SN 1987A, N158A, N49, and N63A (core collapse remnants), 0509−67.5, 0519−69.0, N103B, and DEM L71 (Type Ia remnants). The local star formation histories provide unique insights into the nature of the supernova progenitors, which we compare with the properties of the supernova explosions derived from the remnants themselves and from supernova light echoes. We find that all the core collapse supernovae that we have studied are associated with vigorous star formation in the recent past. In the case of SN 1987A, the time of the last peak of star formation (12 Myr) matches the lifetime of a star with the known mass of its blue supergiant progenitor ($\sim 20\,\mathrm{M}_{\odot}$). More recent peaks of star formation can lead to supernovae with more massive progenitors, which opens the possibility of a Type Ib/c origin for SNRs N158A and N63A. Stars more massive than $21.5\,\mathrm{M}_{\odot}$ are very scarce around SNR N49, implying that the magnetar SGR 0526−66 in this SNR was either formed elsewhere or came from a progenitor with a mass well below the $30\,\mathrm{M}_{\odot}$ threshold suggested in the literature. Three of our four Ia SNRs are associated with old, metal poor stellar populations. This includes SNR 0509−67.5, which is known to have been originated by an extremely bright Type Ia event, and yet is located very far away from any sites of recent star formation, in a population with a mean age of 7.9 Gyr. The Type Ia SNR N103B, on the other hand, is associated with recent star formation, and might have had a relatively younger and more massive progenitor with substantial mass loss before the explosion. We discuss these results in the context of our present understanding of core collapse and Type Ia supernova progenitors.

Subject headings: supernovae: general — supernova remnants — galaxies: stellar content — galaxies: individual: Large Magellanic Cloud

1. INTRODUCTION

The identification of the progenitor stars of supernova (SN) explosions is one of the central problems of stellar astrophysics. In the case of core collapse supernovae (CC SNe: Types II, Ib, Ic, and derived subtypes) the progenitors are known to be massive ($M > 8\,\mathrm{M}_{\odot}$) stars whose inner cores collapse to a neutron star or a black hole. In a few cases, it has been possible to constrain the properties of the progenitor star using pre-explosion images or the turn-off masses of compact clusters (Crockett et al. 2008; Smartt et al. 2008; Vinkó et al. 2009) , but there are still many open issues regarding which stars lead to specific subtypes of CC SNe (for an extended discussion and a complete set of references, see Smartt et al. 2008; Kochanek et al. 2008). In the case of thermonuclear (Type Ia) SNe, the situation is much more complex. Although a CO white dwarf (WD) in some kind of binary is almost certainly the exploding star, the exact nature of the progenitor system has never been firmly established, either theoretically or observationally (see Maoz 2008, and references therein).

When direct identifications are not possible, the properties of the progenitors can be constrained using the stellar populations around the exploding stars. A number of studies have done this for SNe in nearby galaxies (e.g. Hamuy et al. 2000; Sullivan et al. 2006; Aubourg et al. 2008; Modjaz et al. 2008; Prieto et al. 2008; Gallagher et al. 2008), but this approach has important limitations. First, the available information, be it photometric (e.g. Sullivan et al. 2006) or spectral (e.g. Gallagher et al. 2008), is usually integrated over the entire host galaxy, although local measurements at the SN sites have been made for a small number of objects (e.g. Modjaz et al. 2008). This effectively ignores the metallicity and stellar age gradients that must be present in the host. Second, even in surveys that work with complete host spectra, the stellar populations are not resolved. Among other things, this means that the stellar light is weighted by luminosity, which can conceal many important properties of the stellar populations. In practice, the information that can be obtained from this kind of observations is restricted to average metallicities and ages, unless sophisticated fitting techniques are used to extract the star formation history (SFH) of the host (see Aubourg et al. 2008). Ideally, one would want to study *resolved* stellar populations associated with SN progenitors. The information that can be obtained in this way is much more detailed and reliable, but it requires focusing on very nearby SNe.

The present work is the first in a series of papers aimed

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at constraining the fundamental properties of CC and Ia SN progenitors in the Magellanic Clouds by examining the stellar populations at the locations of the supernova remnants (SNRs) left behind by the explosions. To do this, we take advantage of the large amount of observational data accumulated on the stellar populations of the Clouds, in particular the star formation history (SFH) maps published by Harris & Zaritsky (2004) for the SMC and Harris & Zaritsky (2009) (henceforth, HZ09) for the LMC. To identify the sites of recent SNe, we rely on the extensively observed population of SNRs in the MCs (Williams et al. 1999). Much information about the SN explosions can be extracted from the observations of SNRs of both Ia and CC origin (Badenes et al. 2003; Chevalier 2005), and in some cases this information can be complemented by light echoes from the SNe themselves (Rest et al. 2005, 2008). In this first installment, we focus on the eight youngest SNRs in the LMC: SN1987A, N158A, N63A, and N49 (CC SNRs); 0509−67.5, 0519−69.0, N103B and DEM L71 (Ia SNRs).

This paper is organized as follows. In § 2 we describe the criteria that have led to the selection of our eight target SNRs. In § 3 we review their types and the characteristics of the parent SNe that can be inferred from their observational properties. In § 4 we review the fundamental details of the SFH map of the LMC presented in HZ09. In § 5 we discuss the relevance that the local SFH has for the properties of the SN progenitors, given our knowledge about the global SFH and the stellar dynamics of the LMC. In § 6 we examine the local SFHs for the target SNRs, with specific comments relating each SFH to the SNe that originated the SNRs. In § 7 we discuss the impact that our findings have in the context of our current understanding of CC and Ia SN progenitors. Finally, in § 8 we present our conclusions and we outline some avenues for future research.

2. TARGET SELECTION

We will focus on young SNRs because they are usually ejecta-dominated and still contain a great deal of information about their parent SNe - in particular, the risk of mistyping young CC and Ia SNRs is minimal (see § 3). Identifying the youngest SNRs in a given set, however, is not trivial. Among the SNRs in the LMC, only one has a known age (SN 1987A), and only three (0509−67.5, 0519−69.0, and N103B) have more or less accurate age estimates from light echoes (Rest et al. 2005). In the absence of consistent age estimates for all objects, size is the best criterion to select the youngest ones. Much information about the SNR population in the LMC can be found in the *ROSAT* atlas by Williams et al. (1999), but the SNR sizes in particular are not reliable and must be revised. Sizes of SNRs with sharp outer boundaries are overestimated due to the large *ROSAT* PSF (e.g. 0509−67.5, Badenes et al. 2007), while sizes of diffuse SNRs are underestimated due to the low *ROSAT* effective area (e.g. N23, Hughes et al. 2006). We have searched the literature for more recent *Chandra* observations to constrain the LMC SNR sizes, and we have selected the eight smallest objects (sizes < 1.5 arcmin, see Table 1).

The age estimates listed in Table 1 merit a few comments. For SNRs without SN or light echo information, ages are calculated from the SNR size assuming a specific model for the SNR dynamics, which can introduce large uncertainties. In particular, the standard dynamical models for young SNRs (e.g. Truelove & McKee 1999) ignore the effect of cosmic ray acceleration at the forward shock. It is now widely accepted that energy losses due to cosmic ray acceleration can affect the size of young SNRs in a noticeable way (Ellison et al. 2004; Warren et al. 2005), which implies that calculations based on unmodified SNR dynamics can overestimate the age by as much as 20% (see § 5.2 in Badenes et al. 2007, for a discussion).

In Figure 1, we illustrate the location of our eight target SNRs within the large scale structure of the LMC using the data from field 13 of the Southern H-Alpha Sky Survey Atlas (SHASSA, Gaustad et al. 2001). Two SNRs, SN 1987A and N158A, are located in the 30 Dor region, the most prominent active star forming region in the LMC. Two more, N49 and N63A, are in the northern part of the disk, embedded in the North Blue Arm discussed in HZ09 and Staveley-Smith et al. (2003). SNRs 0519−69.0 and N103B are in the outer parts of the LMC bar. The last two objects, 0509−67.5 and DEM L71, are in rather inconspicuous parts of the LMC disk, in the area called the Northwest Void by HZ09. More specific discussions about the location of each SNR will be given in § 6.

3. FROM SUPERNOVAE TO SUPERNOVA REMNANTS: CORE COLLAPSE VS. TYPE IA

3.1. *Typing SNRs*

Typing SNRs as CC or Type Ia can be an uncertain and treacherous business. Both CC and Ia SNe deposit a similar amount of kinetic energy ($\sim 10^{51}$ erg) in the ambient medium (AM), which often makes it impossible to distinguish mature CC from mature Ia SNRs based on their size or morphology alone. A much more reliable way to type SNRs is to examine the evidence left behind by the explosion itself: X-ray spectrum from the SN ejecta and AM, SNR dynamics, and properties of the compact object or pulsar wind nebula (PWN), if present. In general, this can only be done for relatively young objects (but see Hendrick et al. 2003; Rakowski et al. 2006). By using methods along these lines, we have been able to determine the type of all the objects in our list with a high degree of confidence, and in some cases even the SN subtypes within the broader CC and Ia categories. In this Section we will discuss the classification and SN subtypes of our target SNRs, but before going into the details of each object, it is important to mention the work of Chu & Kennicutt (1988). These authors attempted to type *all* the LMC SNRs known at the time by noting the distance from each object to HII regions and OB associations. Although this is a very crude method, their conclusions regarding the CC or Type Ia nature of our target SNRs coincide with ours, except in the case of SNR N103B, which will be discussed in detail in § 3.5 and 6.2.

3.2. *Core Collapse SN Progenitors And Subtypes*

Our theoretical understanding of core collapse SNe is still incomplete (Janka et al. 2007). In particular, the mapping between progenitor mass and CC SN subtype is uncertain, because key processes like stellar mass loss and binary interactions are not well understood (Eldridge & Tout 2004; Eldridge et al. 2008). To set the

stage for further discussions, the stellar evolution models of Eldridge & Tout (2004) for single stars of LMC metallicity ($Z = 0.008$) predict that stars between 8 and 30 $M_\odot$ will explode as red supergiants, retaining most of their H envelope and becoming Type IIP SNe, stars between 30 and 40 $M_\odot$ will lose a large part of their envelopes and explode as Type IIL or Type IIb SNe, and stars above 40 $M_\odot$ will lose all their envelopes and become naked CC SNe of Types Ib and Ic. Within naked CC SNe, there is some evidence that Type Ic SNe, which are linked to long duration gamma-ray bursts (Galama et al. 1998; Stanek et al. 2003) come from more massive stars than Type Ib SNe (Anderson & James 2008; Kelly et al. 2008). Stars that retain a massive H envelope but explode as blue supergiants instead of red supergiants form a separate class, often referred to as SN 1987-like events. The lifetimes associated with these stellar masses range between 41 Myr for an isolated 8 $M_\odot$ star and 5.4 Myr for an isolated 40 $M_\odot$ star (always taking the $Z = 0.008$ models from Eldridge & Tout 2004). In principle, mass loss will be facilitated by binary interactions, leading to fewer red supergiants and more Type Ib/c SNe in binary systems, but stellar evolution calculations that include these effects are subject to an entirely different set of uncertainties (Eldridge et al. 2008).

From the point of view of the SNRs, the complex and turbulent structure of most young CC SNRs makes a quantitative interpretation of the X-ray spectrum in terms of specific explosion models and progenitor scenarios very challenging (e.g. see Laming & Hwang 2003; Young et al. 2006; Park et al. 2007). Many times, it is hard to infer the SN subtype from the observational properties of the SNR, but the large intrinsic diversity of CC SNe as a class can often be used to some advantage in SNR studies. Chevalier (2005) argues that several aspects of SNR evolution are expected to be very different depending on the subtype of the parent SN: mixing in the ejecta, fallback onto the central compact object, expansion of the PWN, interaction with the CSM, and photoionization of the AM by shock breakout radiation. Using arguments along these lines, Chevalier & Oishi (2003) inferred from the positions of the fluid discontinuities, the presence of high velocity H, and the extent of the clumpy photoionized pre-SN wind in the Cas A SNR that its progenitor must have been a Type IIn or Type IIb event. This 'prediction of the past' was later confirmed by the spectroscopy of the light echo of the Cas A SN (Krause et al. 2008a), which is very similar to the spectrum of the Type IIb SN1993J. Although this agreement is certainly encouraging, we must insist that studies based on SNRs are still a long way from providing a robust method of subtyping CC SNe - as an example, the Type IIn/IIb classification of Cas A by Chevalier & Oishi (2003) was challenged by Fesen et al. (2006), who argued for a Type Ib progenitor.

3.3. *Core Collapse SNRs*

In the following paragraphs, we examine each of the four target CC SNRs in more detail. For a summary, see Table 2.

SNR N49— This SNR harbors one of only two magnetars known outside the Milky Way: SGR 0526−66. In principle, the presence of a compact object should immediately classify this object as a CC SNR, but the association between this magnetar and the SNR has been controversial (Gaensler et al. 2001). Even disregarding the compact object, the ejecta emission shows significantly enhanced abundances from O and Si, but a comparatively small amount of Fe (Park et al. 2003), and the SNR is located within the OB association LH53 (Chu & Kennicutt 1988). Taken together, these arguments lend strong support to a CC origin. The complex filamentary structure of the shocked AM suggests that dense material surrounded the SN at the time of the explosion (Bilikova et al. 2007), which favors a progenitor with a slow wind, maybe a Type IIP SN. Unfortunately, this is just an educated guess, because the complex multiphase X-ray emission of the SNR and the poorly known age make the interpretation of the observations very challenging.

SNR N63A— This SNR has no detected compact object, although the upper limits do not exclude the presence of a low-activity PWN (Warren et al. 2003). It is embedded in the large HII region N63, and it also appears to be located within an OB association (NGC 2030, Chu & Kennicutt 1988), making a CC type very likely. The size, morphology, and X-ray spectrum show evident signs of a complex interaction with a highly structured AM, and they seem to indicate that it is expanding into a large cavity (Hughes et al. 1998), which suggests a massive progenitor with a fast wind, maybe a Type Ib/c SN. However, there is no additional evidence to support this conclusion because the X-ray emission, which is dominated by the shocked AM, reveals very little about the properties of the SN ejecta (Warren et al. 2003).

SN 1987A— The classification and subtype of SN 1987A are obvious from the SN spectroscopy. The vast amount of information available on this object is summarized in McCray (2007) and other publications in the same volume. For our purposes, it suffices to mention that the progenitor of this SN is known to have been a blue supergiant star, Sk $-69°202$, whose initial mass has been estimated at $\sim 20\,M_\odot$ (Arnett 1991), and might have been part of a close binary system (Podsiadlowski et al. 1990).

SNR N158A— This object harbors a well-observed PWN that types it as a CC SNR and constrains its age to be $\sim$800 yr (Kirshner et al. 1989; Chevalier 2005). The SN subtype classification has been rather controversial. The SNR dynamics indicate that the shock wave is moving into dense, clumpy CSM similar to what can be found around a massive Wolf-Rayet star, and the presence of strong O and S lines in the X-ray spectrum of the innermost ejecta reveal that at least some of the heavy elements in the ejecta have not fallen back onto the central neutron star (Chevalier 2005). This would favor a massive Type Ib/c progenitor, but both the detection of H in the PWN filaments (Serafimovich et al. 2005) and a recent re-analysis of the ejecta emission (Williams et al. 2008) seem to indicate that the progenitor might have been in the $20-25\,M_\odot$ range, implying a Type IIP explosion (for more detailed discussions, see Chevalier 2006; Williams et al. 2008).

3.4. *Type Ia SN Progenitors and Subtypes*

Our current understanding of Type Ia SN progenitors is still extremely sketchy (Maoz 2008), but several interesting trends have been inferred from the bulk properties the host galaxies. Any theoretical model for Type Ia progenitors must account for the fact that Type Ia SNe explode in elliptical galaxies with very little star formation (SF), but at the same time the rate of Ia events in star forming galaxies appears to scale with the specific star formation rate (Mannucci et al. 2006). Moreover, Type Ia SNe exploding in elliptical galaxies are on average dimmer that those exploding in star forming galaxies (Hamuy et al. 1996; Hamuy et al. 2000). Scannapieco & Bildsten (2005) and Mannucci et al. (2006) used these observational facts to postulate *two* populations of Type Ia SN progenitors: a 'prompt' population with short delay times (of the order of a few hundred Myr), associated with recent SF and leading to somewhat brighter SN Ia, and a 'delayed' population with longer delay times (of the order of Gyr), not associated with recent SF and leading to somewhat dimmer SN Ia. In this two-component model, the specific Type Ia SN rate in a given galaxy is expressed as $SNR_{Ia} = AM_* + B\dot{M}_*$, with M_* being the total stellar mass in the galaxy and $\dot{M}_*$ the specific star formation rate. It is important to stress that the observed rates do not *require* the existence of two components - in some theoretical scenarios, Type Ia SNe from a single progenitor channel can explode with both very short and very long delay times (Greggio et al. 2008). Nevertheless, there have been several attempts to associate the prompt and delayed progenitor populations to the two leading theoretical scenarios for Type Ia SNe: single degenerate (SD) systems, in which the WD accretes material from a non-degenerate companion and double degenerate (DD) systems, in which the WD accretes material from another WD. So far, none of these attempts has succeeded (see f.i. Förster et al. 2006; Greggio et al. 2008), and the identity of Type Ia SN progenitors remains a mystery.

Despite all the uncertainties regarding their progenitors, Type Ia SN explosions as a class are much more homogeneous and have less intrinsic dispersion than CC SNe. In particular, there is a simple relationship between the structure of the ejecta and the peak brightness of the SN that is well reproduced by one-dimensional delayed detonation (DDT) explosion models (Mazzali et al. 2007). This allows to map the vast majority of SN Ia onto a sequence of bright to dim events based on the amount of ^{56}Ni that they synthesize. Generally speaking, Type Ia SNRs are also much less turbulent than CC SNRs, and most of them seem to be interacting with a relatively unmodified AM (Badenes et al. 2007), although there are exceptions like the Kepler SNR (Reynolds et al. 2007) and SNR N103B (Lewis et al. 2003, , see also the discussion in § 7.2). Thanks to this set of circumstances, it is generally easier to interpret the X-ray emission of Type Ia SNRs quantitatively in terms of specific explosion models, provided that the dynamic evolution of the SNR and the nonequilibrium processes in the shocked plasma are properly taken into account (Badenes et al. 2003; Badenes 2004; Badenes et al. 2005). It is also possible to estimate the brightness of the parent event from the mass of ^{56}Ni synthesized by the preferred DDT explosion model, as shown by Badenes et al. (2006) in the case of the Tycho SNR.

3.5. *Type Ia SNRs*

These four objects were classified as Type Ia SNRs by Hughes et al. (1995) based on their lack of compact object or PWN and the general properties of their X-ray emission, which is dominated by Fe lines and has only weak or absent lines from O. In order to confirm these classifications and derive the SN subtype, it is necessary to perform an in-depth analysis of the ejecta emission, as done by (Badenes et al. 2008b) for SNR 0509−67.5. The X-ray emission of the other three objects will be the subject of a forthcoming publication (Badenes & Hughes 2009, henceforth BH09), but the main results of that analysis are presented in the following paragraphs, and summarized in Table 3.

SNR DEM L71— This is the oldest object in our Type Ia SNR list, and the only one without a light echo age estimate. Ghavamian et al. (2003) determine an age of 4360 ± 290 from the SNR dynamics, and yet the X-ray spectrum appears dominated by shocked Fe from the SN ejecta, specially in the center (Hughes et al. 2003). The old age of this SNR makes the analysis of the ejecta emission somewhat challenging, but BH09 find that it can be reproduced by DDT models for normal Type Ia SNe.

SNR N103B— This object was initially classified as a CC SNR by Chu & Kennicutt (1988) based on its location at the edge of the HII region DEM 84 and 40 pc away from the OB association NGC 1850. However, the X-ray spectrum is strongly suggestive of a Type Ia origin (Hughes et al. 1995; Lewis et al. 2003). The SNR is also remarkable in that it shows a strong east-west asymmetry (Lewis et al. 2003), which has been interpreted as a sign of some kind of CSM interaction, mainly by analogy to the Kepler SNR. This asymmetry also makes the ejecta analysis challenging, but BH09 find a relatively good match to the spectrum using DDT models for moderately bright Type Ia SNe with a SNR age close to the 800 yr estimated from the light echo by Rest et al. (2005).

SNR 0509–67.5— Next to SN1987A, this SNR has the most secure subtype classification in the LMC. In 2008, two teams analyzed independently the optical spectrum of the SN light echo (Rest et al. 2008) and the X-ray emission and dynamics of the SNR (Badenes et al. 2008b), and came to the same conclusion: SNR 0509−67.5 was originated ~ 400 yr ago by an exceptionally bright Type Ia SN that synthesized $\sim 1\,M_\odot$ of ^{56}Ni. This agreement is a very important validation of the modeling techniques introduced in Badenes et al. (2003) that BH09 apply to the other three target Type Ia SNRs, and in particular of the capability of the models to recover the SN subtype[6].

SNR 0519–69.0— The final object in our Type Ia SNR list has an estimated age of 600 ± 200 yr from its light

[6] The recent spectroscopic analysis of the light echo from Tycho's SN by Krause et al. (2008b) also confirms the previous result by Badenes et al. (2006) based on the X-ray emission from the SNR that the SN was of normal brightness, not overluminous or underluminous.

echo (Rest et al. 2005). Its X-ray emission is well reproduced by a moderately bright Type Ia SN model that synthesizes $0.8\,M_\odot$ of ^{56}Ni (BH09).

4. OVERVIEW OF THE STAR FORMATION HISTORY MAP OF THE LMC

The SFH map that we use in the present work is described in full detail in HZ09. The map was elaborated using four band (U, B, V, and I) photometry from the Magellanic Clouds Photometric Survey (Zaritsky et al. 2004), which has a limiting magnitude between 20 and 21 in V, depending on the local degree of crowding in the images. Data from more than 20 million stars was assembled to produce color-magnitude diagrams in 500 $24' \times 24'$ cells encompassing the central $8^\circ \times 8^\circ$ of the LMC (see Figure 4 in HZ09), and then the StarFISH code (Harris & Zaritsky 2001) was applied to derive the local SFH for each cell. Cells with enough stars in them, like the eight cells that contain our target SNRs, were further subdivided into four $12' \times 12'$ subcells. The SFH of each cell is given at thirteen lookback times between $Log(t) = 6.8$ (6.3 Myr) and $Log(t) = 10.25$ (17.8 Gyr), and it is broken into four metallicity bins: $Z = 0.008$, 0.004, 0.0025, and 0.001.

For reference in further discussions, we reproduce the SFH of the entire LMC from HZ09 in Figure 2. The error bars on the total SFH represented with the gray shaded area are dominated by crowding effects (see § 3.3 in HZ09). Although no metallicities were fitted for ages below 50 Myr, the plots display the canonical LMC metallicity ($Z = 0.008$) in the most recent age bins, which is reasonable in view of the high degree of homogeneity in the metallicity of the ISM and the young stars in the LMC (Pagel et al. 1978; Russell & Dopita 1990; Korn et al. 2002; Hunter et al. 2007). A detailed discussion of the SFH of the LMC and its interpretation in the context of the LMC's past history can be found in § 5 of HZ09. For our purposes, it suffices to note that, after an initial episode of SF in the distant past, the LMC went into a quiescent period that lasted until 5 Gyr ago, and since then it has been forming stars at an average rate of $0.2\,M_\odot yr^{-1}$, with episodes of enhanced SF at 2 Gyr, 500 Myr, 100 Myr, and 12 Myr. From Figure 2, it is obvious that the vast majority of the stars in the LMC have ages above 1 Gyr. Most of these old stars have metallicities of one tenth solar or lower.

5. ON THE RELEVANCE OF THE LOCAL STELLAR POPULATIONS TO SUPERNOVA PROGENITORS

During the lifetime of a galaxy, several processes naturally mix the stellar populations. These include both internal processes like the 'churning' of the disk by spiral arms (Sellwood & Binney 2002) and external processes like tidal interactions and mergers (Mihos & Hernquist 1994). In this context, the properties of the stellar population (and hence the SFH) in the neighborhood of a young SNR will only be representative of the SN progenitor up to a certain lookback time, t_{lb}. In principle, t_{lb} can be calculated for each location within a galactic disk provided there is a viable dynamic model that includes all the relevant processes. Unfortunately, no such model exists for the LMC, despite the wealth of observational information available. The LMC disk is warped (Nikolaev et al. 2004) and might also be flared (Subramanian & Subramaniam 2008), and it has a rich history of tidal interactions with the SMC and (maybe) the Milky Way, which may have important effects on the stellar dynamics (see Olsen & Massey 2007; Besla et al. 2007). The vestigial arms seen in HI (Staveley-Smith et al. 2003) are probably originated by these tidal interactions, but the details of this process are not well understood (Besla et al. 2007). Even the nature of the most prominent feature in the disk - the LMC bar - and its role in the dynamics of the galaxy are unclear (Zaritsky 2004).

Without a reliable way to calculate t_{lb} for each of the subcells that contain our target SNRs, all we can do is estimate the relevant timescales for a number of different processes. The physical size of the subcells in the HZ09 map is 350×350 pc (assuming $D = 50$ kpc, Alves 2004), and the velocity dispersions for the young disk and old disk populations determined by Graff et al. (2000) are 8 and $22\,\mathrm{km\,s^{-1}}$, respectively. Thus, the length of time that it would take an average star of the young (old) disk to drift from one subcell to the next in the absence of restoring forces, t_d, is 43 (16) Myr. These timescales are not relevant for the progenitors of CC SNe, which should belong to the young disk, but they will be very important for SN Ia progenitors, which could be quite older. In any case, t_{lb} should be much larger than t_d, because (a) some regions of the LMC are more homogeneous than others, which means that stars have to drift over larger distances in order to find substantially different stellar populations, and (b) there are restoring forces like gravity that maintain the structural integrity of the disk and act to limit stellar drift.

We have quantified the spatial homogeneity of the stellar populations around our target SNRs in Figure 3. We plot the absolute value of the relative differences in the stellar populations as a function of the distance from the center of each of the eight subcells that contain the CC and Ia SNRs in our list. To calculate the relative differences, we have integrated the SFH in each neighboring subcell, taking all the time bins were the differences between the neighbor and the SNR subcell were statistically significant (i.e., the error bars did not overlap) up to a lookback time of 1.1 Gyr, and then divided by the total number of stars formed in the SNR subcell. At each distance, the relative difference is the mean of the relative differences between the SNR subcell and all the subcells at that distance. Figure 3 shows that some of our target SNRs are in remarkably homogeneous regions of the LMC disk. These include the CC SNRs N49 and N63A in the Blue Arm and the Type Ia SNR 0509−67.5 in the Northwest Void, with average relative differences in the stellar populations below 15% within 1400 pc of the central subcell. This distance translates into t_d values of 215 and 80 Myr for young and old disk stars in the absence of restoring forces.

The effect of restoring forces on the value of t_{lb} is more difficult to estimate. If no chaotic processes intervene, neighboring stars will tend to move together through the disk, which explains why some LMC structures like the bar and the Northwest Arm show up in the HZ09 map with lookback times as large as 1 Gyr (see their Figure 8). This long survival time is not restricted to large structures - in the Solar neighborhood, there is evidence that several groups of old stars (2 to 8 Gyr) are moving to-

gether through the disk of the Milky Way (Dehnen 1998). But smaller structures like young stellar clusters seem to disappear on timescales of the order of 180 Myr in the LMC (Bastian et al. 2008), which is roughly equivalent to the dynamic crossing time of the LMC disk. We will adopt this value as a figure of merit for t_{lb} in a single subcell of the SFH maps. Since the result of Bastian et al. (2008) applies to young stars, this implies that restoring forces increase the value of t_d by at least a factor ~ 4, but we stress that this is just a very rough estimate.

We conclude that the relevance of the local SFHs for Type Ia SN progenitors will depend on both the homogeneity of the stellar populations around each subcell (Figure 3) and the age of the progenitors. If the lifetime of Type Ia progenitors in the prompt channel is as short as the 180 Myr claimed by Aubourg et al. (2008), it should be possible to use the local SFHs of Type Ia SNRs in the LMC to explore their properties. For progenitors with longer lifetimes, the stellar context of each SNR should be taken into account. Objects like SNR 0509−67.5 might allow exploration of timescales up to several hundred Myr, but SNRs like 0519−69.0 probably will not.

6. STAR FORMATION HISTORIES AROUND THE TARGET SNRS

The local SFHs in the subcells containing the eight SNRs in our list are plotted in Figures 4 and 6. The lifetime of an isolated $8\,M_\odot$ star with $Z = 0.008$ from Eldridge & Tout (2004) has been indicated by a dashed vertical line in all the plots for illustrative purposes. For simplicity, we have collapsed all the SFH bins at ages above 2 Gyr into a single bin at 10 Gyr. Several interesting average quantities can be calculated from the local SFHs. We have listed two such quantities in Tables 2 and 3: the average metallicity of all the stars formed in the subcell, $\bar{Z_*}$ and their average age $\bar{t_*}$. These averages are always dominated by the large population of old stars in each subcell, and therefore they are irrelevant for the properties of CC SN progenitors - the values in Table 2 are merely provided for comparison with the values in Table 3 (see discussion in § 7). The average values for the entire LMC are $\bar{Z_*} = 0.0023$ and $\bar{t_*} = 8.1$ Gyr.

6.1. *Core Collapse SNRs*

The most salient feature of the SFHs around the four CC SNRs (Figure 4) is that they are strongly dominated by intense bursts of star formation in the recent past ($t < 40$ Myr). This is of course expected, and in the cases where the SNRs have been typed for their close proximity to young stellar clusters (notably, SNR N63A), it does not reveal any new information. However, the timing of these bursts and their intensity will determine the properties of the population of massive stars that can be found at each location, and hence the likelihood of each CC SN subtype. To highlight these aspects, we display the most recent bins of the SFHs associated with the CC SNRs in greater detail in Figure 5, alongside the lifetimes of isolated massive stars with $Z = 0.008$ from Eldridge & Tout (2004) [7]. We have convolved the three most recent SFH bins with a standard Salpeter IMF to calculate the fraction of massive stars that are exploding now as CC SNe (f_{CCSN}) from progenitors in three mass intervals: 8 to $12.5\,M_\odot$, 12.5 to $21.5\,M_\odot$ and above $21.5\,M_\odot$. We list these fractions in Table 2 for each of the CC SNRs. The interval cuts are the stellar masses whose lifetimes correspond to the upper edges of the first and second age bins in the SFHs: 9.4 and 18.9 Myr. We remind the reader that these values of f_{CCSN} are calculated using isolated star models that do not take into account the potentially large effects of binarity on stellar evolution. An entirely different but also potentially serious problem comes from the fact that massive stars are notoriously difficult to study using photometry alone (Massey et al. 1995). Because StarFISH uses *all* the stars (not just the massive ones) in each subcell to calculate the SFR at each age, the values of f_{CCSN} might not be severely affected by this, but to this date there has been no systematic calibration of the StarFISH results for young stellar populations. To reflect these and other caveats, we do not list error bars on the f_{CCSN} values, which should only be regarded as approximate.

SNR N49— The integrated SFH for the North Blue Arm region that contains SNR N49 and SNR N63A is dominated by a coherent episode of low-metallicity star formation 100 Myr ago (see § 5.1.3 and Figure 16 in HZ09), which is apparent in the corresponding panels of Figure 4. This is the reason why the values of $\bar{Z_*}$ and $\bar{t_*}$ for SNRs N49 and N63A are lower than those of the other SNRs. Many parts of the North Blue Arm have also had noticeable star formation activity in the last 40 Myr, although not as intense as in the more prominent star forming regions of the LMC, 30 Dor and Constellation III. SNR N49 is in one such region, which had a moderately intense SF burst 12 Myr ago, but very little SF activity in the most recent bin centered at 6.3 Myr (see Figure 5). From these properties of the SFH, the expectation is that the majority of the CC SN progenitors in this subcell should be stars between 12.5 and $21.5\,M_\odot$ (see Table 2). Even taking the upper limit of the SFR in the most recent bin and the lower limit on the bin at 12 Myr, the fraction of CC SN progenitors with masses above $21.5\,M_\odot$ remains below 1%, with all the caveats associated to the calculated values of f_{CCSN}. This is in good agreement with the properties of the SNR discussed in § 3.3, and it has interesting implications for the association of SNR N49 with SGR 0526−66. Magnetars are thought to be originated by very massive ($> 30\,M_\odot$) stars (Gaensler et al. 2005; Figer et al. 2005; Muno et al. 2008), but such stars appear to be very scarce around SNR N49. One possibility is that the magnetar was formed elsewhere and the association is coincidental. Gaensler et al. (2001) examined this issue in detail, and came to the conclusion that the link between SNR N49 and SGR 0526−66 is considerably less convincing than those of other magnetars in SNRs. More recently, Klose et al. (2004) performed a NIR survey of the area around SNR N49 and identified a young stellar cluster (SL 463) at a projected distance of ~ 30 pc northeast of SGR 0526−66 that could have been the birthplace of the magnetar. This cluster does fall partially on a neighboring subcell of the HZ09 map with intense SF at 6.3 Myr, consistent with the 5 to 20 Myr age estimates for SL 463 by Klose et al.,

[7] Other grids of stellar models (e.g. Maeder & Meynet 1989; Girardi et al. 2000) can give slightly different values for the lifetimes of isolated stars of LMC metallicity. In general, these differences are not large enough to have an impact on our work.

and much more promising as a birthplace of massive CC progenitors (36% above $21.5\,\mathrm{M}_{\odot}$). As pointed out by Klose et al., if this hypothesis is true the magnetar must have been ejected from its birthplace with a certain velocity, and should have a measurable proper motion (see their § 3.2). Another possibility is that the association between SNR N49 and SGR 0526−66 is indeed real, but not all magnetars have stellar progenitors more massive than $30\,\mathrm{M}_{\odot}$.

SN 1987A — The SFH associated with this SNR is of particular interest because, together with the known mass of the progenitor, $\sim 20\,\mathrm{M}_{\odot}$, it can provide some test of the robustness of our SFH approach to CC SN progenitors. Panagia et al. (2000) conducted a detailed study of the immediate neighborhood of SN1987A within the 30 Dor region using *HST* data, and found a loose young cluster with an age of 12 ± 2 Myr, which they identified as the birthplace of SN1987A's progenitor. The local SFH drawn from the HZ09 map is indeed dominated by an intense SF episode 12 Myr ago, in good agreement with the results of Panagia et al. (2000). From the SFH, we expect 56% of the CC SN progenitors in this region to be stars between 12.5 and $21.5\,\mathrm{M}_{\odot}$ (see Figure 5). This agreement is encouraging, and indicates that some information about the progenitor mass of CC SNe can be recovered from the SFH maps of HZ09.

SNR N63A — Like SNR N49, SNR N63A is located in a part of the Blue Arm with SF activity in the recent past. The SFH in this subcell, however, is different from that around SNR N49 in that it is dominated by the most recent bin centered at 6.3 Myr. As a result, 70% of the CC SN progenitors in this subcell are expected to be stars more massive than $21.5\,\mathrm{M}_{\odot}$. With a Salpeter IMF, roughly 40% of these stars will be in turn more massive than $40\,\mathrm{M}_{\odot}$, which makes a Type Ib/c origin for SNR N63 plausible, as suggested by the properties of the SNR. If this were true, SNR 63A would be one of the youngest nearby Type Ib/c SNRs, and a closer examination of this object to locate the elusive compact object and study the ejecta emission in greater detail would be of the highest interest.

SNR N158A — This object is also located in 30 Dor, but in a region with even more vigorous recent SF than the neighborhood of SN 1987A. According to our estimates, 24% of the CC SN progenitors in this subcell should be stars more massive than $21.5\,\mathrm{M}_{\odot}$. Again, this is compatible with the relatively massive progenitor suggested by the SNR properties (see § 3.2), but unfortunately the temporal resolution of the SFH does not allow us to discriminate between a Type IIP progenitor with $20 - 25\,\mathrm{M}_{\odot}$ (Williams et al. 2008) and a Type Ib/c progenitor with $> 40\,\mathrm{M}_{\odot}$ (Chevalier 2005). From the point of view of the stellar population around SNR 158A, both hypotheses are equally plausible.

6.2. *Type Ia SNRs*

The local SFHs around the four Type Ia SNRs are displayed in Figure 6. Since the age of the progenitors is not known *a priori*, we also display the integrated SFHs in Figure 7 to provide a more intuitive picture of the makeup of the stellar populations in these locations and how they have evolved with time. With one exception (SNR N103B, see below), these SFHs are very different from those associated with the CC SNRs. The SFHs of SNRs DEM L71, 0509−67.5, and 0519−69.0 show very little (but nonzero) activity in the last 200 Myr, resulting in old and metal poor stellar populations, typical of the regions of the LMC without ongoing star formation. The SFHs of these three SNRs are also punctuated by bursts of SF at 600 Myr and 2 Gyr whose prominence varies from object to object, but this is probably more related to the global properties of the LMC (see Figure 2) than to the Type Ia SN progenitors.

Given the coincidence of the LMC disk crossing time and the upper limit for the delay time of short-lived SN Ia progenitors (180 Myr according to Aubourg et al. 2008, see § 5), it is possible to use the A+B model introduced in § 3.4 and the local SFHs to predict what fraction of Type Ia SNe will come from prompt and delayed progenitors in each subcell (f_{IaSN}). For the prompt component, we have calculated an average star formation rate by integrating the SFHs between 64 Myr (the minimum time necessary to produce a CO WD at the metallicity of the LMC, Dominguez et al. 1999) and 180 Myr, and we have multiplied it by the value of B from Sullivan et al. (2006), $3.9 \pm 0.7 \times 10^{-4}\,\mathrm{SNe\,yr^{-1}}\,(\mathrm{M}_{\odot}\,\mathrm{yr}^{-1})^{-1}$. For the delayed component, we have simply multiplied the number of stars in each subcell by the value of A from Sullivan et al. (2006), $5.3 \pm 1.1 \times 10^{-14}\,\mathrm{SNe\,yr^{-1}\,M_{\odot}^{-1}}$. The values of f_{IaSN} for each Type Ia SNR are listed in Table 3, and can be compared with the values obtained for the whole LMC using the integrated SFH from Figure 2: $f_{IaSN,Prompt} = 59\%$ and $f_{IaSN,Delayed} = 41\%$. Even more so than in the case of CC SNe, we stress that these numbers should be considered with caution, because they make strong assumptions about the properties of Type Ia SN progenitors. In particular, increasing the upper limit to the age of the prompt component from 180 to 300 Myr results in an increase of the fraction of *delayed* Type Ia progenitors between 8 and 15 percentual points, depending on the SNR.

At a first glance, it is somewhat surprising that the SN Ia rates from prompt and delayed progenitors are always comparable both in the whole LMC and at the locations of the individual Type Ia SNRs. This can be easily understood by examining Figure 6 in Sullivan et al. (2006): for low values of the SFR, the *specific* rate of Type Ia SNe from the prompt and delayed components is very similar, and low-intensity SF has been widespread across the LMC during the last 5 Gyr (see § 4 and HZ09).

SNR DEM L71 — The exceptionally low rate of SF between 64 and 180 Myr in the subcell containing this SNR makes it the most likely object (72% probability) to be associated with a delayed Type Ia SN progenitor. Unfortunately, DEM L71 is also the oldest Type Ia SNR, and detailed information about its parent SN is hard to extract from the observations. In particular, the ejecta emission is not remarkable in any way, and seems consistent with normal Type Ia SN explosion models (BH09). The forward shock is running into material with a factor ~ 3 density range (Ghavamian et al. 2003), but this can be easily explained by inhomogeneities in the ISM. The SNR dynamics do not indicate any substantial modification of the AM by the progenitor (Badenes et al. 2007).

SNR N103B— Of all the SFHs associated with Type Ia SNRs that we discuss here, that of SNR N103B is without doubt the most remarkable. This SNR is in a region of the LMC bar that has seen vigorous SF activity in the recent past, with a prominent extended peak between 100 and 50 Myr (probably associated to the nearby cluster NGC 1850, Gilmozzi et al. 1994) and a more recent one 12 Myr ago. The intensity of this last peak is even larger than those associated with SN 1987A and SNR 158A in the 30 Dor region. It is not surprising that Chu & Kennicutt (1988) mistyped SNR N103B as a CC SNR before a good quality X-ray spectrum was available, based on this evident association with recent SF. This does not necessarily imply that the progenitor of SNR 103B was a young star, although the predicted fraction of prompt Ia progenitors (73%) is higher for this SNR than for any of the others. However, if the properties of the SNR itself are taken into account, the association with recent SF becomes more intriguing. Lewis et al. (2003) noted a number of similarities between the strong lateral asymmetry of SNR N103B and that of Kepler's SNR. In the case of SNR N103B, it is unclear whether this asymmetry is due to an interaction with an ISM structure (e.g., the nearby HII region DEM 84) or to some kind of CSM modified by the SN progenitor. In the Kepler SNR, however, it has been shown that the asymmetry is indeed due to interaction with a CSM modified by the Type Ia SN progenitor (see Reynolds et al. 2007, and references therein), suggesting that either the progenitor or its companion must have been relatively massive. From the shape of the SFH, a relatively young (less than 150 Myr) and metal-rich ($Z = 0.008$) progenitor for SNR N103B seems a likely possibility.

SNR 0509–67.5— This SNR is in a region that HZ09 called the Northwest Void due to its conspicuous lack of recent star formation. In fact, HZ09 argue that the old and metal-poor stars in this part of the LMC are representative of the primordial stellar population of the LMC. Moreover, the SNR is in a very homogeneous region (see Figure 3), with neighboring subcells having very similar stellar populations. The closest subcells with noticeable SF activity (above $10^{-3}\,\mathrm{M_\odot yr^{-1}}$) at $t < 100$ Myr are roughly 1 kpc away from the SNR. This would not be noteworthy for a generic Type Ia SNR, but thanks to the work of Rest et al. (2008) and Badenes et al. (2008b) we know that SNR 0509−67.5 was originated by an exceptionally bright Type Ia SN which synthesized $\sim 1\,\mathrm{M_\odot}$ of ^{56}Ni. This seems to be at odds with the conventional wisdom regarding prompt and delayed Type Ia SN progenitors, which holds that exceptionally bright Type Ia SNe are usually associated with younger stellar populations (Gallagher et al. 2005), but in fact the local SFH predicts equal contributions from prompt and delayed progenitors even in this remarkably quiet part of the LMC. If this SNR did have a relatively young and massive progenitor, however, it appears to have left the AM around it relatively undisturbed (Badenes et al. 2007, 2008b).

SNR 0519–69.0— This SNR falls in line with 0509−67.5 and DEM L71 in having a low SFH at all times, although the local stellar population appears to be more metal rich than in the other Type Ia SNRs (see Figure 7). Other than that, SNR 0519−69.0 is unremarkable both in its overall structure and dynamics and in the properties of its ejecta emission. From the local SFH, delayed Type Ia progenitors are slightly favored over prompt ones, but not significantly.

7. DISCUSSION

7.1. *Core Collapse Supernovae*

The combination of SNR studies and local SFHs that we have introduced in this paper is a promising method to further our understanding of CC SN progenitors, but it needs to be refined before it can have a significant impact on this field of research. Two major issues need to be addressed. First, the techniques used to determine the subtype of CC SNe from their SNRs are still too crude to provide consistent results, even for well observed objects like the CC SNRs in our sample. And second, the ability of tools like StarFISH to recover the SFH from mixed stellar populations at the ages that are relevant for the evolution of CC SN progenitors (below 40 Myr) using photometric data needs to be firmly established. It would be interesting to investigate the possibility of an increased temporal resolution at very early times (less than 10 Myr) in order to distinguish between Type IIL/b and Type Ib/c SN progenitors, but this might require support from spectroscopic surveys like the VLT-FLAMES (Evans et al. 2006). We hope to address these issues in future publications.

Despite the limitations of the method, we have been able to obtian some interesting results. In general, we can say that the properties of the SNRs and the local SFHs are compatible with each other, allowing for the large uncerainties discussed above. Among our target objects, the SFH around SNR N49 seems to indicate that stars more massive than $21.5\,\mathrm{M_\odot}$ are scarce in this part of the LMC. This opens two possibilities: either very massive ($> 30\,\mathrm{M_\odot}$) stars are not necessary to produce magnetars, or the source SGR 0526−66 is not in fact associated with SNR N49, as suggested by (Klose et al. 2004). The SFH around SNR N63A seems compatible with a very massive SN progenitor, maybe a Type Ib/c SN, but other possibilities cannot be discarded. For SNR 158A, the temporal resolution of the HZ09 maps is too coarse to resolve the issue of the progenitor. In any case, our findings stress the importance of revisiting and reanalyzing the X-ray emission from these young CC SNRs in detail to learn more about the SN explosions that originated them.

7.2. *Type Ia Supernovae*

We have found that the combination of SNR studies and local SFHs is a powerful tool to explore the properties of Type Ia SN progenitors. The X-ray emission from Type Ia SNRs is well understood in terms of explosion physics, and the ability of SNR studies to recover the Type Ia SN subtype (i.e., bright vs. dim) has been demonstrated by Badenes et al. (2008b). Moreover, the combination of StarFISH and a data set like the MCPS is ideally suited to characterize the stellar population in different parts of the LMC.

Among the Type Ia SNRs that we have studied, one (SNR N103B) is found in a region that has experienced vigorous SF in the recent past, but the other three are associated to old and metal-poor stellar populations. On a first inspection, it would be tempting to establish connections between these two kinds of environments and

the prompt and delayed components to Type Ia progenitors proposed by Scannapieco & Bildsten (2005), but we have found that the situation is more complex than that. Even in regions with a remarkably small amount of recent SF, it is very hard to isolate objects that arise unambiguously from delayed Type Ia progenitors. This is due to the high efficiency of the still unknown mechanisms that turn CO WDs from relatively young, intermediate-mass stars into Type Ia SN progenitors of the prompt component (Mannucci et al. 2006; Pritchet et al. 2008; Maoz 2008). In order to identify with some confidence a Type Ia SNR as a product of the prompt or delayed component, it would have to be either in a region with very vigorous SF or in a pristine region with no measurable SF activity in the appropriate range of ages. Since even elliptical galaxies appear to have some residual SF during their entire lifetimes (Kaviraj et al. 2008), isolating the delayed Type Ia progenitors in the local universe to study their properties in detail might be a very challenging task, unless a Type Ia SN is found in a nearby globular cluster (Shara & Hurley 2002).

Our results allow us to test specific theoretical predictions about Type Ia progenitors, like the claim by Kobayashi et al. (1998) that the Type Ia SN rate should be very low for metallicities lower than a tenth of the solar value. This is based on the so-called 'accretion wind' scenario for single-degenerate Type Ia progenitors, which requires a minimum opacity in the material transferred from the companion to the WD (Hachisu et al. 1996). The average *stellar* metallicity is close to this value or even much lower around three of the four Type Ia SNRs that we have examined, which seems hard to reconcile with the results of Kobayashi et al., although we stress that all the regions that we examined do contain a small number of stars with higher metallicities. Similar concerns about this prediction and its implications have been raised by Prieto et al. (2008), who found several Type Ia SNe in low-metallicity dwarf galaxies. The accretion wind scenario also makes strong predictions about the shape of the CSM around Type Ia progenitors that are not substantiated by the dynamics of known Type Ia SNRs (Badenes et al. 2007). In this context, an interesting possibility is opened by the recent work of Badenes et al. (2008a), which allows one to make *direct* measurements of the metallicity of Type Ia SN progenitors using Mn and Cr lines in the X-ray spectra of young SNRs. If this technique could be applied to the LMC SNRs, we would be able to contrast the results with the properties of the stellar populations, and test theoretical ideas about the role of metallicity in different kinds of Type Ia SNe (e.g. Timmes et al. 2003).

Two of the SNRs we have examined have remarkable properties with important implications for Type Ia SN progenitors. The unusual morphology of SNR N103B (see Lewis et al. 2003, and references therein), which is strongly suggestive of some kind of CSM interaction, has become even more noteworthy in light of the vigorous recent SF revealed by the local SFH. It appears that SNR N103B might be a member of an emerging class of Type Ia SNRs with CSM interaction that could be associated with relatively young and massive progenitors that lose an appreciable amount of mass before exploding as Type Ia SNe. This class would include the Kepler SNR (Reynolds et al. 2007) in our Galaxy and other LMC SNRs (Borkowski et al. 2006), but the local SFHs around these objects should be examined to confirm this possibility. Evident signs of CSM interaction, however, cannot be found in other well studied Type Ia objects like Tycho and SN 1006 in our own Galaxy or the other three LMC SNRs that we have analyzed here (Badenes et al. 2007), indicating that a majority of Type Ia progenitors do not modify their surroundings in a noticeable way. Since it is unlikely that *all* these other objects have had progenitors from the delayed component, we are left with two possibilities: either the amount of mass loss during the pre-SN evolution of prompt Type Ia progenitors has a large dynamic range or there is more than one way to produce Type Ia SNe with short delay times.

The properties of SNR 0509−67.5 are also remarkable, for entirely different reasons. Rest et al. (2008) found $\Delta m_{15} < 0.9$ for this SN, which translates into to a V magnitude at maximum light close to -19.5 (Phillips 1993). Yet, the SN exploded in a large region of the LMC with very little SF in the recent past (see Figure 3). The stars in the subcell that contains this SNR are on average very old ($\bar{t_*} = 7.9$ Gyr) and metal-poor ($\bar{Z}_* = 0.0014$). Gallagher et al. (2008) do find some relatively bright Type Ia SNe associated with old stellar populations, but all their objects with peak V magnitude above -19 and ages above 5 Gyr have large error bars on the age axis (see their Figure 5). Thus, SNR 0509−67.5 is probably the first *bona fide* example of an exceptionally bright Type Ia SN associated with an old stellar population. We note that our measurement of $\bar{t_*}$ should be very reliable, because it has not been derived from a luminosity-weighted spectrum. It is important to stress that these bulk properties of the stellar population around SNR 0509−67.5 do not preclude a relatively young progenitor for this object. During the age range that we have adopted for prompt Type Ia progenitors, $2.1 \times 10^4\,\mathrm{M}_\odot$ of stars were formed in the subcell that contains SNR 0509−67.5. With a Salpeter IMF, roughly 10% of this mass is in the 4 to 6 $\mathrm{M}_\odot$ range (the ZAMS masses that give CO WDs on timescales shorter than 180 Myr according to Dominguez et al. 1999), which results in a few hundred CO WDs from young stars. This number may seem small, but observational constraints on the percentage of CO WDs that eventually explode as SN Ia are high (2 to 40 % according to Maoz 2008), making a prompt progenitor for SNR 0509−67.5 a perfectly reasonable possibility. The fact that an object like SNR 0509−67.5 appears in a sample of only four SNRs implies that bright Type Ia SNe in old stellar populations may not be an exceptional occurrence, which should be taken into account when examining the contribution of bright and dim Type Ia SNe in cosmological studies.

Our results underline the dangers of trying to understand the behavior of Type Ia SN progenitors by studying only the bulk properties of unresolved stellar populations in distant galaxies. If the LMC had been a distant Type Ia SN host, two objects with such radically different SFHs as SNRs N103B and 0509−67.5 would have been assigned the same age and metallicity. Even average quantities obtained from resolved stellar populations like $\bar{t_*}$ and $\bar{Z}_*$ can be misleading if they are used by themselves to characterize the properties of SN progenitors - compare the values for CC and Type Ia SNRs from Tables 2 and 3.

8. CONCLUSIONS

In this paper, we have presented the first systematic study of the stellar populations around CC and Type Ia SNRs in the LMC. Our ultimate goal is to use all the available information on the X-ray emitting SNRs and the resolved stellar populations of the Magellanic Clouds to improve our understanding of CC and Type Ia SN progenitors, their final evolutionary stages, the SN explosions that mark their demise, and the aftermath of these explosions. In that broad context, this work only represents a first exploration of the many possibilities that are opened by recent theoretical and observational advances in both SNR research and stellar population studies. We plan to pursue this line of research in the future, increasing the sample of objects and refining the techniques that we have presented here.

We have found that the local SFHs around the CC SNRs in our sample (N49, SN 1987A, N63A, and N158A) are always dominated by significant episodes of SF in the recent past ($t < 40$ Myr), as expected from previous observational and theoretical work. The timing and intensity of these SF episodes can provide interesting constraints on the masses of CC SN progenitors, but more work is needed to explore the full potential of this method.

The local SFHs have also allowed us to study the ages and metallicities of the stellar populations around our target Type Ia SNRs (DEM L71, N103B, 0509−67.5, and 0519−69.0) in great detail. We have found that Type Ia SNe explode in a variety of environments, ranging from old and metal-poor populations to sites with vigorous SF in the recent past. Using the two-component model proposed by Scannapieco & Bildsten (2005), we have explored the relationship between specific properties of Type Ia SNe and their parent stellar populations. We have seen that extremely bright Type Ia SNe can explode very far away from any significant star formation activity (SNR 0509−67.5), and that Type Ia SNe associated with young stellar populations might sometimes experience significant mass-loss before they explode (SNR N103B). Recent studies of extragalactic Type Ia SN rates and our own findings suggest that reality is probably too complex to be explained with the popular two-component progenitor model. If this is so, high-quality SFHs for Type Ia SNRs obtained from resolved stellar populations like the ones we present here should provide an excellent observational constraint on new ideas about Type Ia progenitors.

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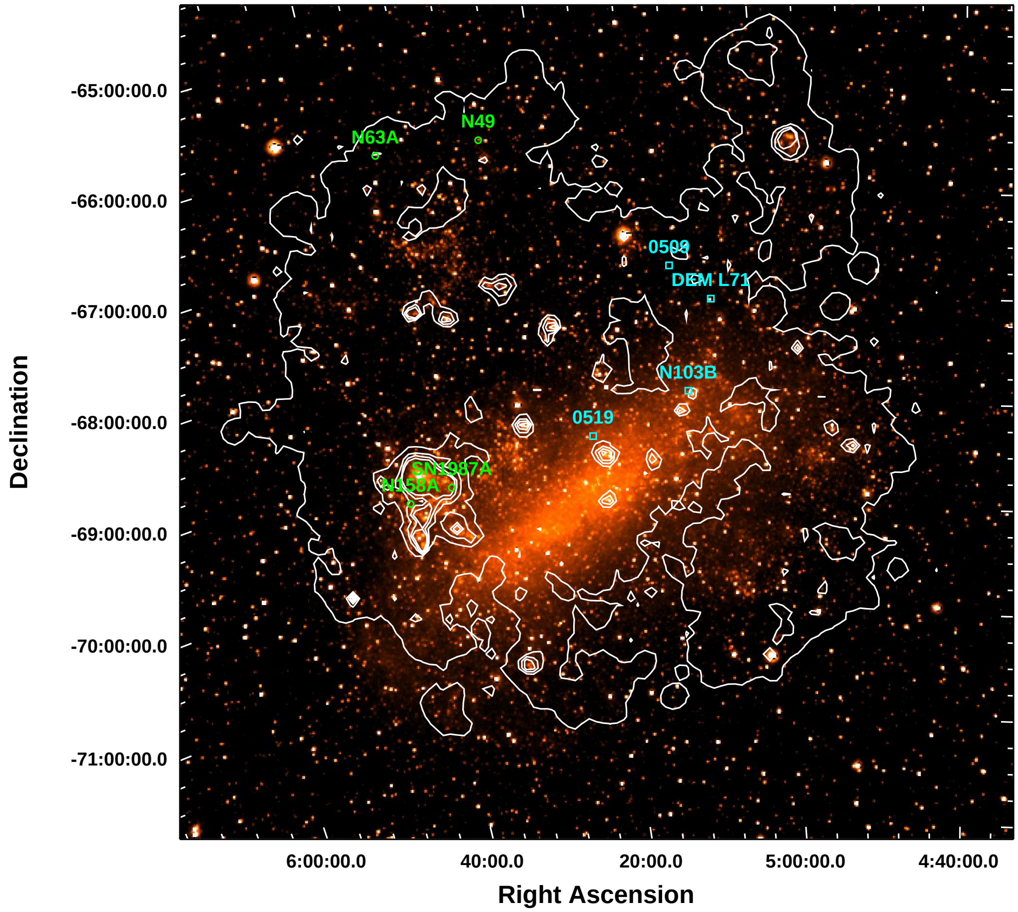

FIG. 1.— Map of the LMC in the SHASSA continuum band, indicating the positions of the eight target SNRs (core collapse SNRs with green circles, Type Ia SNRs with cyan squares). The overlaid contours are from the Hα SHASSA image, which highlights the LMC disk, the W, S, and B spiral arms (Staveley-Smith et al. 2003), and the 30 Dor region around SN 1987A and N158A.

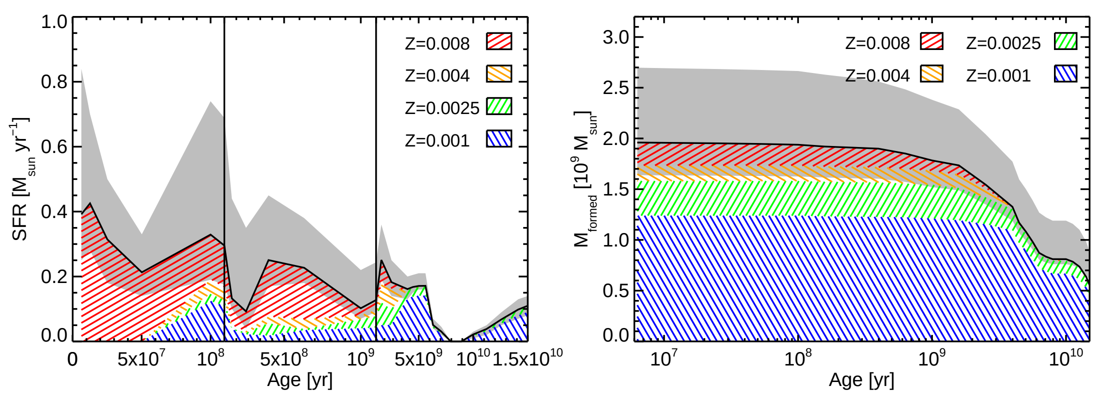

FIG. 2.— Total SFH of the LMC, broken into four metallicity bins. Left panel: star formation rate (SFR) as a function of lookback time. This plot is drawn following the style of HZ09 in three linear-linear panels that highlight the structure of the SFH at short (0 to 110 Myr), medium (110 Myr to 1.1 Gyr) and large (1.1 Gyr and beyond) lookback times. The gray area represents the error on the total SFR. Right panel: integrated SFR displaying the cumulative stellar mass formed in the LMC as a function of lookback time. Adapted from Figure 11 in HZ09.

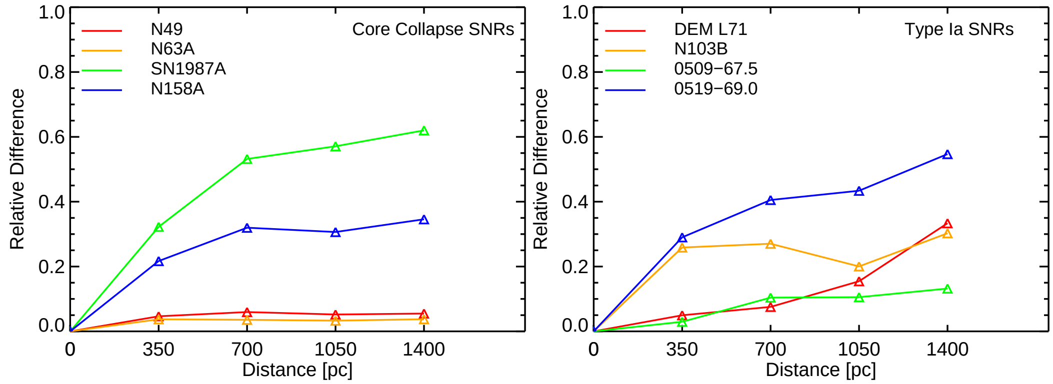

FIG. 3.— Relative difference in the stellar populations as a function of distance from the center of the subcells containing our eight target SNRs. Left panel: core collapse SNRs; right panel: Type Ia SNRs.

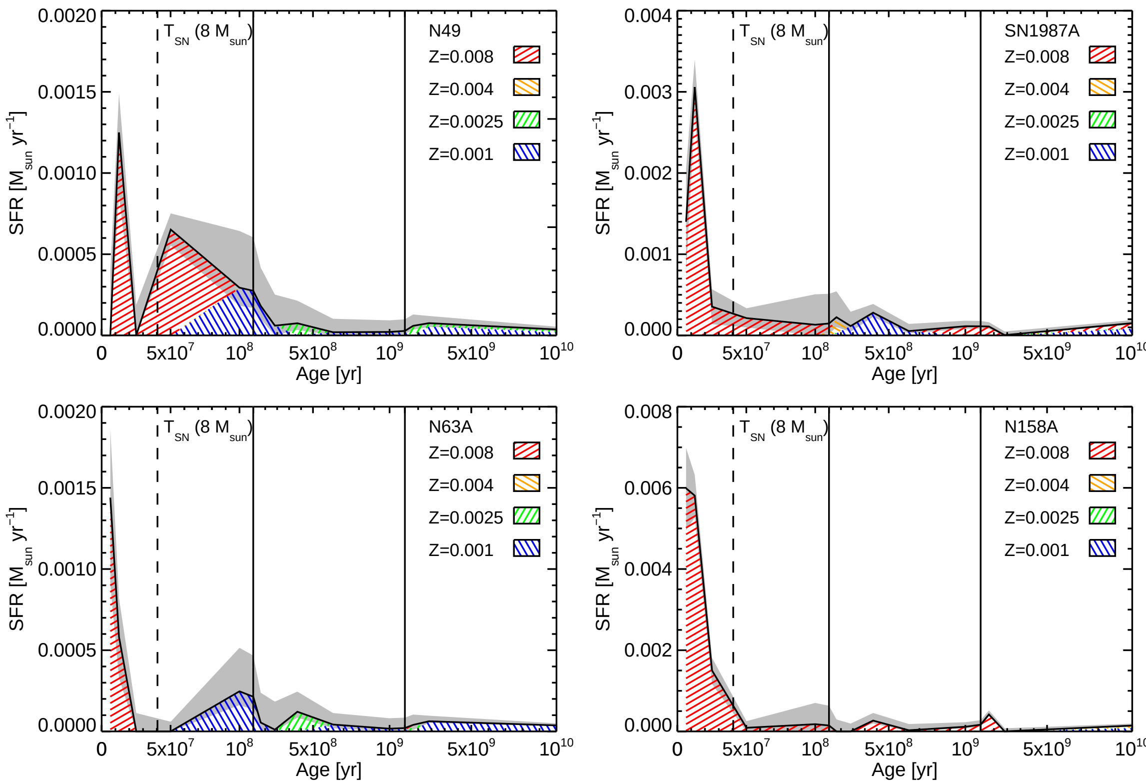

FIG. 4.— Local SFHs around the four target core collapse SNRs. See Figure 2 for an explanation of the plots.

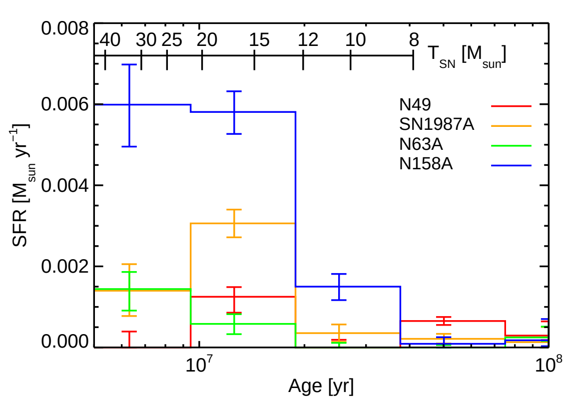

FIG. 5.— Detail of the recent SFH around the four target CC SNRs. The lifetimes of isolated stars of LMC metallicity with different masses are displayed on the ruler on top of the plot.

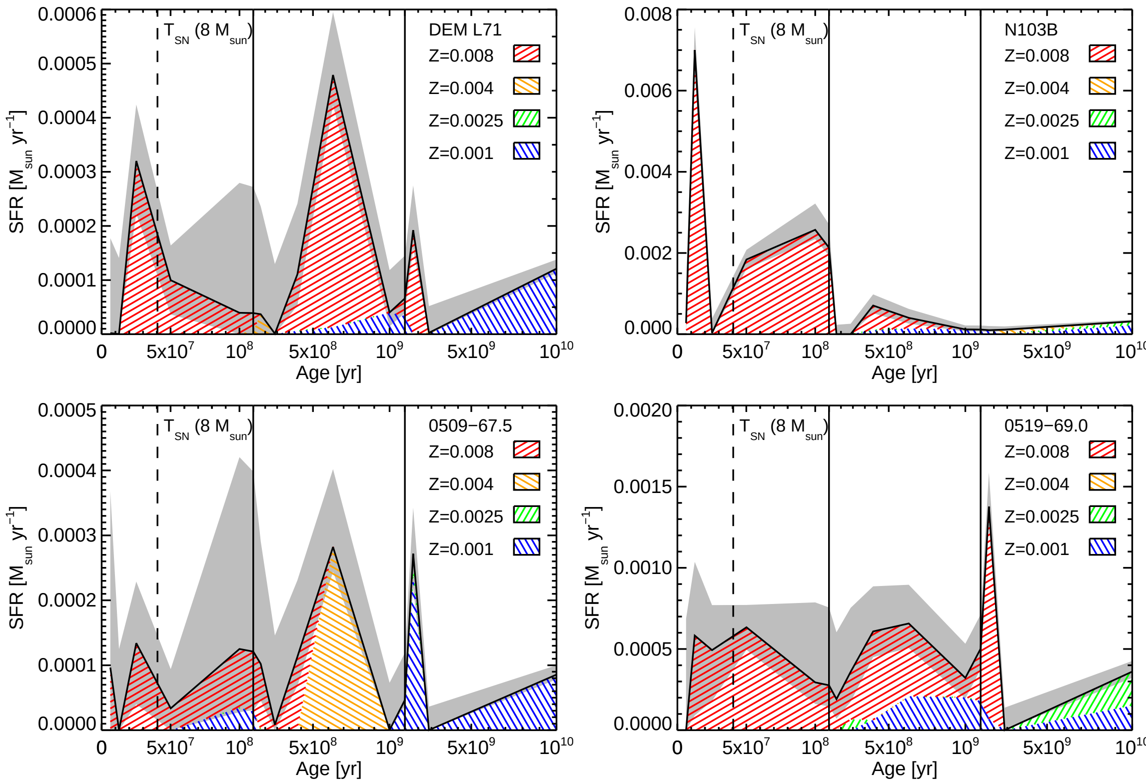

FIG. 6.— Local SFHs around the four target Ia SNRs. See Figure 2 for an explanation of the plots.

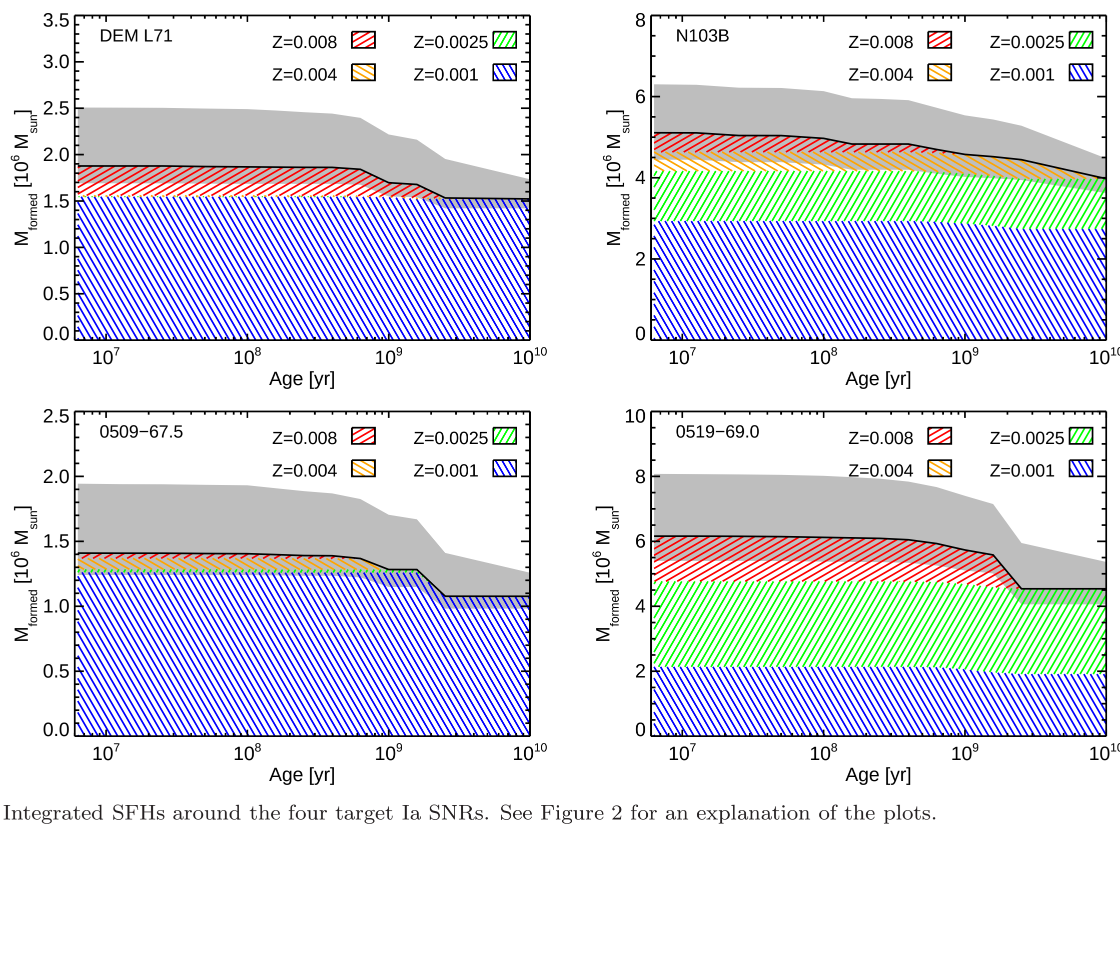

FIG. 7.— Integrated SFHs around the four target Ia SNRs. See Figure 2 for an explanation of the plots.

TABLE 1
YOUNG SUPERNOVA REMNANTS IN THE LARGE MAGELLANIC CLOUD

SNR [a]	Common Name	Position (J2000) [b] RA	Dec	Size (arcmin)	Age (yr)	Age Estimation Method
0505−67.9	DEM L71	05h 05m 42s	-67d 52m 39s	1.4x1.0 (H03)	4360 ± 290 (G03)	SNR Dynamics [c]
0509−68.7	N103B	05h 08m 59s	-68d 43m 35s	0.46 (B07)	∼860 (R05)	Light Echo
0509−67.5		05h 09m 31s	-67d 31m 17s	0.48 (B07)	400 ± 50 [d] (B08,R05)	Light Echo
0519−69.0		05h 19m 35s	-69d 02m 09s	0.52 (B07)	600 ± 200 (R05)	Light Echo
0525−66.1	N49	05h 26m 00s	-66d 04m 57s	1.4 (P03)	6300 ± 1000 (V06)	SNR Dynamics [c]
SN 1987A	SN 1987A	05h 35m 28s	-69d 16m 11s	0.03 (N08)	22	SN
0535−66.0	N63A	05h 35m 44s	-66d 02m 14s	1.1 (W03)	3500 ± 1500 (H98)	SNR Dynamics [c]
0540−69.3	N158A	05h 40m 11s	-69d 19m 55s	1.3x0.7 (H01)	∼800 (C05)	Pulsar

REFERENCES. — B07: Badenes et al. (2007); B08: Badenes et al. (2008b); C05: Chevalier (2005); G03: Ghavamian et al. (2003); H01: Hwang et al. (2001); H03: Hughes et al. (2003); H98: Hughes et al. (1998); N08: Ng et al. (2008); P03: Park et al. (2003); R05:Rest et al. (2005); R08: Rest et al. (2008); V06: Vink & Kuiper (2006); W03: Warren et al. (2003)
[a] By convention, LMC SNRs are designated in this abbreviated form using the RA and Dec of their center in J1950 coordinates. For more details on the SNR names, see Williams et al. (1999).[b] From Williams et al. (1999).[c] Ages estimated from SNR dynamics are subject to substantial uncertainties. See text for details.[d] The age from the light echo dynamics is 400 ± 120 yr (Rest et al. 2005), but the spectral and dynamical properties of the SNR, together with some historical considerations, constrain the value much more, see discussion in § 5.3 of Badenes et al. (2008b).

TABLE 2
CORE COLLAPSE SUPERNOVA REMNANTS

SNR	CC Typing Criteria [a]	Subtype classification	$\bar{Z}_*$ [b]	$\bar{t_*}$ [b] (Gyr)	f_{CCSN} (in %) 8 to 12.5 $M_\odot$	12.5 to 21.5 $M_\odot$	$> 21.5\,M_\odot$
N49	OB (C88), CO? (G01)	Unknown (IIP?, B07)	0.0018	6.0	0	100	0
SN 1987A	SN	1987-like/IIpec	0.0043	8.7	20	56	24
N63A	OB (C88)	Unknown (Ib/c?, H98)	0.0013	6.4	0	30	70
N158A	CO (K89)	IIP (W08) or Ib/c (C05)	0.0036	7.8	30	36	34

REFERENCES. — B07: (Bilikova et al. 2007);C88: Chu & Kennicutt (1988); C05: Chevalier (2005); K89: Kirshner et al. (1989); G01: Gaensler et al. (2001); H98: Hughes et al. (1998); W03: Warren et al. (2003); W08: Williams et al. (2008)
[a] OB: in or very close to an OB association. CO: compact object. SN: SN spectroscopy.[b] These values are provided for comparison with the Type Ia SNe listed on Table 3, and do not reflect the properties of the progenitor stars of the CC SNRs.

TABLE 3
TYPE IA SUPERNOVA REMNANTS

SNR	Ia typing Criteria	Subtype Classification [a]	$\bar{Z}_*$	$\bar{t_*}$ (Gyr)	f_{IaSN} (in %) Prompt	Delayed
DEM L71	X-ray (H95)	Normal? (BH09)	0.0022	8.3	28	72
N103B	X-ray (H95)	Bright? (BH09)	0.0023	8.1	73	27
0509−67.5	X-ray (H95)	Very bright (B08,R08)	0.0014	7.9	49	51
0519−69.0	X-ray (H95)	Bright (BH09)	0.0032	7.7	41	59

REFERENCES. — B08: Badenes et al. (2008b); BH09: Badenes & Hughes (2009); H95: Hughes et al. (1995); R08: Rest et al. (2008)
[a] The subtype corresponds to the estimated brightness of the SN inferred from the mass of ^{56}Ni in the best-fit model for the X-ray spectrum of the SNR: Very bright ($\sim 1\,M_\odot$ of ^{56}Ni), bright ($\sim 0.8\,M_\odot$ of ^{56}Ni) normal ($\sim 0.6 - 0.4\,M_\odot$ of ^{56}Ni), and dim ($\sim 0.3\,M_\odot$ of ^{56}Ni).